Talk at AccApplic kick-off meeting, 14 June 2013, Geneve

Introduction to industrial applications (a tentative view)

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1) Low energy accelerators < 10 MeV and other; introduction

2) Electron application

3) Ion application

4) Some other notable application

1) Introduction: accelerator CURRENT vs VOLTAGE vs COST

It is difficult to summarize all important industrial application of accelerators

So, let me note some items to be discussed (perhaps biased towards electrostatic accelerators).

Purpose of network is actually to assemble a more complete view

+) MOST APPLICATION TYPICALLY NEED LARGE CURRENTS

$I = PV^{3/2}$ with perveance $P = k_0 f$

For one round aperture

$$f = \frac{2\pi(1-\cos\theta)}{\alpha^2} \cong O(1)$$

$$k_0 = \frac{4\epsilon_0}{9}\sqrt{\frac{2|q|}{m}}$$

Langmuir α > 0.3 to obtain a point focus,

***θ* spherical cathode semiaperture [rad]**

Example 10000 V, f=1 implies electron current 2.33 A, but H- ion 54 mA

This favours electrons, when nuclear physics <u>does not request otherwise</u>.
Electron sources are also cheaper than ion sources

One glorious industrial application for electron accelerators has almost died: the Cathode Ray Tube (CRT) for television set.

About or over 25000 accelerators (without CRT and common X-ray tubes) installed in the world (regulatory agencies knows better*). Most are for

A) medical application

B) material modification

with cost/unit distribution peaked below few ME (I guess) and energy <10 MeV. Hundred of units are at research institutes(*), with cost/unit distribution peaked over 10 ME (I know). Typically these units was for high energy or nuclear physics, but now research accelerator are involved into applications as

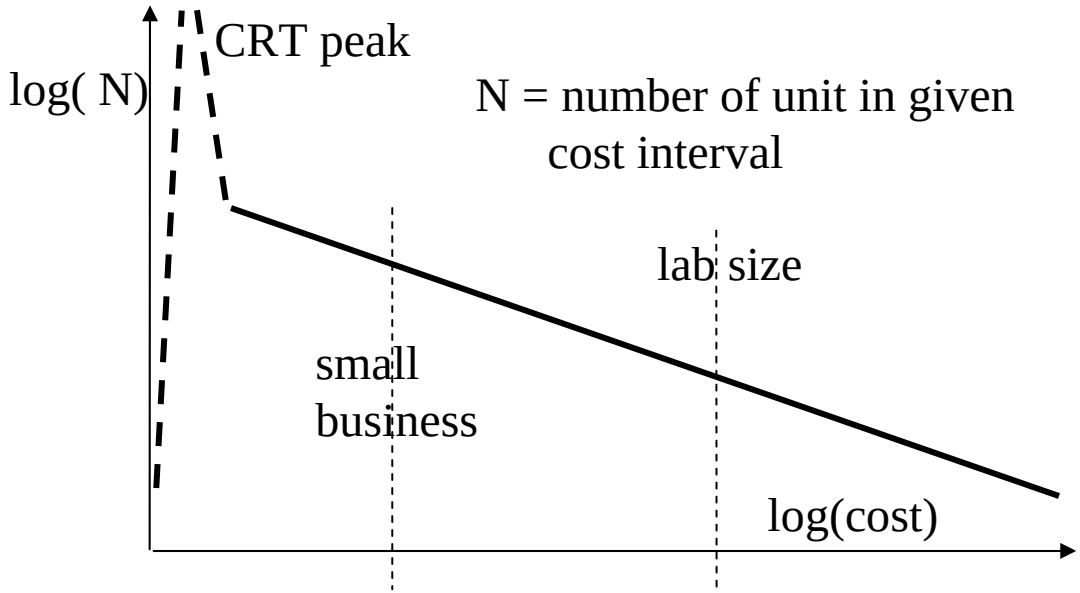


Figure: a guess of cost distribution of accelerators

C1) Spallation Neutron Sources

Synchrotron Light Sources

Ion Beam Sources (say C^{4+} for medical treatment),

(*)Nuclear physics applications are well monitored. Info

http://www-pub.iaea.org/MTCD/publications/PDF/P1433_CD/datasets/summary.html

Mullhauser, AccApp '11 - Tenth International Topical Meeting on Nuclear Applications of Accelerators

C2)Material analysis and processing:

accelerator mass spectrometry

fission waste certification

fission waste burning (hopefully),

neutron production (yield , spectra)

production of radioisotopes (RI) for several medical treatments

non-RI isotope separation (calutrons or PSP, plasma separation process)

art manufacture inspections

C3) Energy production development:

Accelerator Driven system for fission,

Neutral Beam Injection for fusion.

It may be hoped that advance in material, accelerator and particle source physics from C activities will propagate to A and B

ELECTRON APPLICATION

0) The electron microscope (need not current, but very well focused beam)

1) Electron welding

2) Irradiation of materials:

polymers cross-linking (it may improve voltage holding, flame resistance, etc.)

textile industry (an ideal thin target)

food sterilization

flue gas treatment, air pollution control (see following talk)

3) Light production:

FEL (Vela project, see following talk)

Synchrotron light

X-ray tubes

Microwave tubes

ION APPLICATION

1) Sputtering and thin film deposition

2) Lithography of chips, etc

3)Neutron production (with protons) with designed spectra; see dr Pisent talk: MUNES-INFN (5 MeV proton)

4) Irradiation of materials (see dr Kulevoy talk, ITEP). At top size range, IFMIF project (40 MeV deuterons)

5) Separation of non radioactive isotopes (calutrons, or plasma separation process)

Es: ^{102}Pd (1% natural abundance, used to produce ^{103}Pd for medical app)

Es: ^{235}U (0.7% natural abundance, dismissed in favor of other methods) [J. Dawson, F.F. Chen]

Es: ^{100}Mo (9.6% natural abundance, used to ultimately to produce ^{99}Tc for medical app)

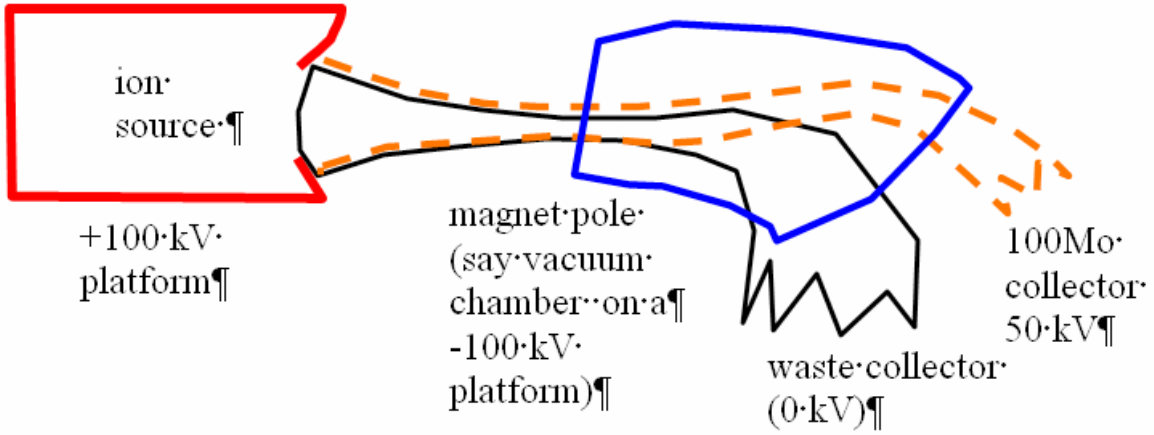


Figure: sketch of energy-wise calutron for a 0.5 A total beam current (round beam)

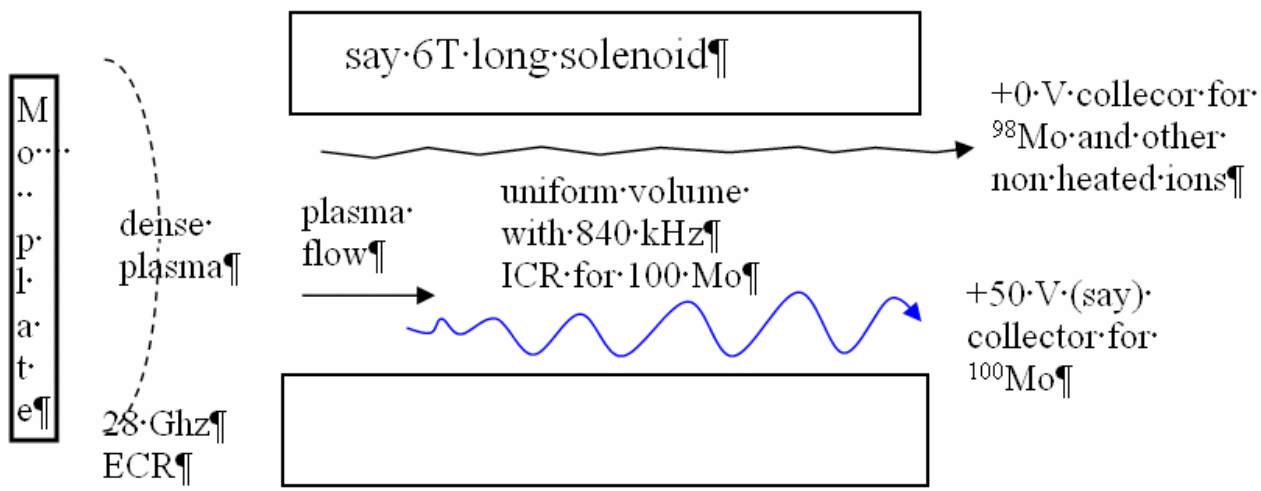


Figure: PSP principle [Dawson 1976, Muromkin 2013]; in a Mo plasma flow, only ^{100}Mo is heated, and can arrive on a biased collector plate. With 1 m bore magnet, 10 A total ion current are well feasible (50 A maybe)

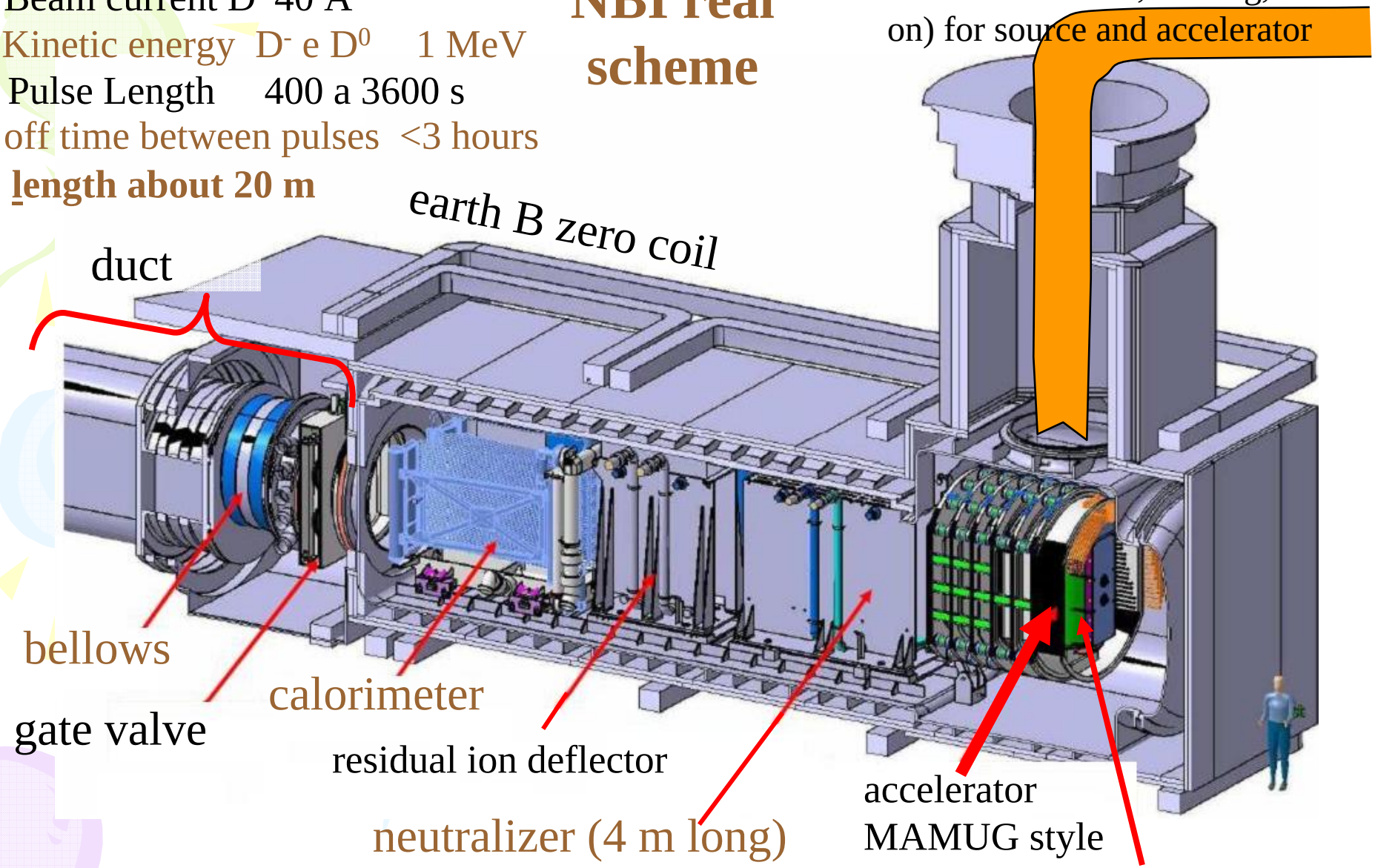
4) OTHER APPLICATIONS

In case fusion rectors will work, a reasonable market may be Neutral Beam Injectors, under development (also at Padua, Consortium RFX including INFN)

Typical size 1 MeV energy, up to 55 A current D^-, 20 m length

NBI real scheme

Beam current D^- 40 A
Kinetic energy D^- e D^0 1 MeV
Pulse Length 400 a 3600 s
off time between pulses <3 hours
length about 20 m



3D view of a neutral ion injector [adapted from P.Sonato, RFX, 2009]; MAMUG = MultiAperture MUlti Grid.